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APOLLO LAUNCH-VEHICLE MAN-RATING: SOME CONSIDERATIONS AND AN ALTERNATIVE CONTINGENCY PLAN (U)

E. D. Harris and J. R. Brom

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The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA • 90406

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PREFACE

This Memorandum identifies and discusses some considerations involved in man-rating the Saturn 5 launch vehicle for the Apollo program. Because possible delays in the man-rating schedule would delay the lunar landing, this Memorandum also suggests a contingency plan that would allow the Apollo lunar-landing mission to be carried out without using a man-rated Saturn 5, but otherwise using Apollo systems in nearly their normal configurations. The plan is developed in concept; numerous technical details remain to be solved. The intent is to provide background information and operational-planning suggestions to those in the Apollo program at the policy-making and program-guidance level.

Although the study focuses on Project Apollo, the problem considered and the suggested solution would apply in concept to other manned space programs. Therefore, the usefulness of this Memorandum could extend beyond the Apollo program to other programs of NASA and DOD.

This Memorandum documents a brief study for man-rating contingency planning for the Apollo program performed by The RAND Corporation for Headquarters, National Aeronautics and Space Administration, under Contract NASr-21(10).

SUMMARY AND CONCLUSIONS

This Memorandum examines the problem of launch-vehicle availability for manned Apollo flights. The extent of the launch-vehicle flight-test programs for the Apollo program is examined and compared with those of Mercury and Gemini. It is found, for example, that if one ignores the large number of missile launches for Mercury and Gemini, then the extent of the unmanned flight-testing is essentially the same for all three manned space-flight programs. Although NASA planning has undoubtedly taken into full account the size and complexity of the Saturn 5 launch vehicle, the magnitude of this program is such that one cannot exclude the possibility that more flights than those presently planned may be required.

Since the consequences of an increased number of unmanned Saturn 5 launches are higher costs and the possibility of missing the Apollo goal, lunar landing and return before 1970, a contingency plan may be desirable. Although current Apollo contingency plans provide for many potential problem areas, they still require the Saturn 5 to be man-rated before the operational (manned) Apollo mission can be undertaken, even at the risk of missing the 1970 goal. Recognizing that many of the problems that may postpone man-rating Saturn 5 do not affect its payload-delivery capability, this Memorandum suggests a contingency plan consisting of an earth-orbit rendezvous for transferring the astronauts from a ferry vehicle to the lunar-mission Apollo spacecraft as an alternative mode of operation.

It must be emphasized that the contingency plan discussed in this Memorandum is not the same as the so-called Earth Orbit Rendezvous (EOR) mode of operation considered and discarded as a plan for the Apollo program; nor does it diverge significantly from current Apollo hardware approaches and mission profile. The preferred ferry vehicle is found to be the man-rated Saturn 1B, with partly fueled Apollo Command and Service Modules as its payload. Use of this combination would provide sufficient velocity potential (about 5000 fps) for rendezvous, catch-up maneuvers, and a reasonable plane change (maximum of 10 deg); would not significantly affect the Apollo crew-training or life-support systems; and need not require any additional procurement of spacecraft or launch vehicles to support the first lunar-landing mission. A shroud-type device, similar to the Lunar Excursion Module drogue, that allows docking of two Apollo Command Modules is the item with the longest lead time--about one year. Thus, the decision for implementation of the suggested contingency plan can be delayed until after the first Saturn 5 launch; this will allow an assessment of the status of both the launch vehicle and spacecraft during a late stage of development.

The consideration of whether the astronauts or spacecraft should be placed into earth orbit first depends upon the rendezvous technique and the orbital limitation of the third stage of the Saturn 5 (S-IVB). It appears that in order to minimize the S-IVB earth-orbit stay time, the astronauts should be placed into orbit first (with an alternative mission objective in case of subsequent difficulties with the launch vehicle). Although this approach lengthens the mission for the astronauts, it is not critical in view of the anticipated demonstration of a 14-day capability. However, the feasibility of accomplishing the earth-orbit-rendezvous mission discussed in this Memorandum while remaining within the Saturn third-stage operating limits (about 10 hr) needs to be studied further. In this regard, it would be desirable for Gemini to demonstrate a fast catch-up and rendezvous operation; this would assist in establishing such items as tolerable launch-time errors, preferable catch-up maneuvers, and the feasibility of a dog-leg maneuver during launch of the second vehicle in the Apollo earth-orbit rendezvous. The results from the study of the third-stage limitations and the above Gemini experiments should be available prior to the first Saturn 5 launch (1967) to assist NASA in making a decision concerning the contingency plan suggested in this Memorandum.

The utility of the earth-orbit-rendezvous contingency plan is not limited to just the case where a large number of additional Saturn 5 flights are necessary to satisfy the Saturn 5's man-rating objective. Even in the event that only one or two additional unmanned Saturn 5 flights are found to be necessary for man-rating, the lunar mission could be attempted earlier in the program if the contingency plan suggested in this Memorandum is employed during the early Saturn 5 flights. The time saved in the above case may be relatively small, i.e., three or four months per flight, if the scheduled Saturn 5 launch frequency is realized. However, if the launch frequency is lower than anticipated, particularly during the early phase of the Saturn 5 flight-test program, then the program time saved by the use of the earth-orbit-rendezvous contingency plan might be quite significant. Hence, one objective of the suggested contingency plan is to provide a means of attempting the lunar-landing mission as early as possible in the Apollo program without a significant increase in the program cost or complexity.

The earth-orbit-rendezvous mode of operation may also have other applications. One such area discussed in this Memorandum is that of spacecraft weight growth. For example, if Saturn 5 is modified to accommodate further spacecraft weight increases, then the use of an earth-orbit rendezvous for transferring the astronauts would allow earlier operational use of the uprated Saturn 5 launch vehicles.

ACKNOWLEDGMENTS

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CONTENTS

I. INTRODUCTION

The availability of the man-rated Saturn 5 launch vehicle is a critical item for the satisfactory accomplishment of the Apollo mission as currently planned. The purpose of this Memorandum is (1) to examine some of the factors affecting the availability of the Saturn 5 for operational (manned) missions, and (2) to discuss a contingency plan that could be implemented should Saturn 5 experience unexpected developmental problems. A general review was made of the Mercury and Gemini space programs for related missile experience, which was examined and compared with the programs planned for the Apollo launch vehicle. This background survey suggests the need for a readily implementable contingency plan that would use Apollo hardware with only minimal changes in vehicle configurations and mission profile.

The problems involved in man-rating the Apollo launch vehicle and the current flight-mission assignments and contingency plans are discussed. Although these contingency plans account for a variety of situations that may be encountered in the Apollo program, they still require both the spacecraft and the the Saturn 5 launch vehicle to be man-rated before undertaking the lunar-landing mission. Since these man-rating requirements may delay the Apollo mission beyond the 1970 goal, an alternative contingency plan is presented that would eliminate the necessity for man-rating Saturn 5 but still use the Apollo vehicles in their normal mission configurations. The effect of this plan, which uses an earth-orbit rendezvous, on the present Apollo hardware and schedule and on the possible problem of Apollo spacecraft weight escalation is also discussed. It also is possible that use of this contingency plan might result in a significant time savings even in the event that Saturn 5 experiences only a minor delay in man-rating.

II. LAUNCH-VEHICLE MAN-RATING CONSIDERATIONS

In view of the current dependence of the Apollo mission on the availability of a man-rated Saturn 5 launch vehicle, this section examines some of the considerations involved in achieving an operational Saturn 5 at an early date. Apollo is the only U.S. manned space-flight program that will use launch vehicles developed specifically for manned flight. The other two programs, Mercury and Gemini, used converted missiles as their launch vehicles. These missiles, the Atlas D and Titan II, respectively, were modified by (1) eliminating missile-unique components and (2) adding an abort system.[1] Since this conversion did not affect the basic launch vehicles, their relevant flight-test histories were examined in order to help define the problems involved in man-rating. These histories and the scheduled plans for the three manned space-flight programs are presented in Fig. 1.

The incremental-development philosophy for the Saturn series of launch vehicles allows NASA to use the results of the earlier flight tests in order to improve subsequent vehicles. For example, Saturn 1 and 1B have essentially the same first stage (S-I), and the second stage of Saturn 1B (S-IVB) is also used as the third stage of Saturn 5 (see Table 1). Figure 1, which includes the cumulative number of flights for each of the Saturn stages, shows that while only three unmanned flights are scheduled for both Saturn 1B and Saturn 5 before the first manned flight, additional stage flights contribute to the development experience (see Table 2 also). The S-I stage, for example, will have a test history of 13 flights at the time of the first scheduled manned mission for Saturn 1B, although the S-IVB stage will have been flown only three times. Table 2 presents similar figures for Saturn 5.

Although the fourth Saturn 5 flight is scheduled to be manned (Fig. 1), NASA has planned for additional launch vehicles in case unexpected problems develop which necessitate extending the unmanned Saturn 5 flight phase; 15 Saturn 5 vehicles have been procured, the thirteenth of which is scheduled for flight during the last of 1969 (Fig. 1). Since two manned flights are scheduled prior to the lunar landing,* a total

*See Table 4 in Section III.

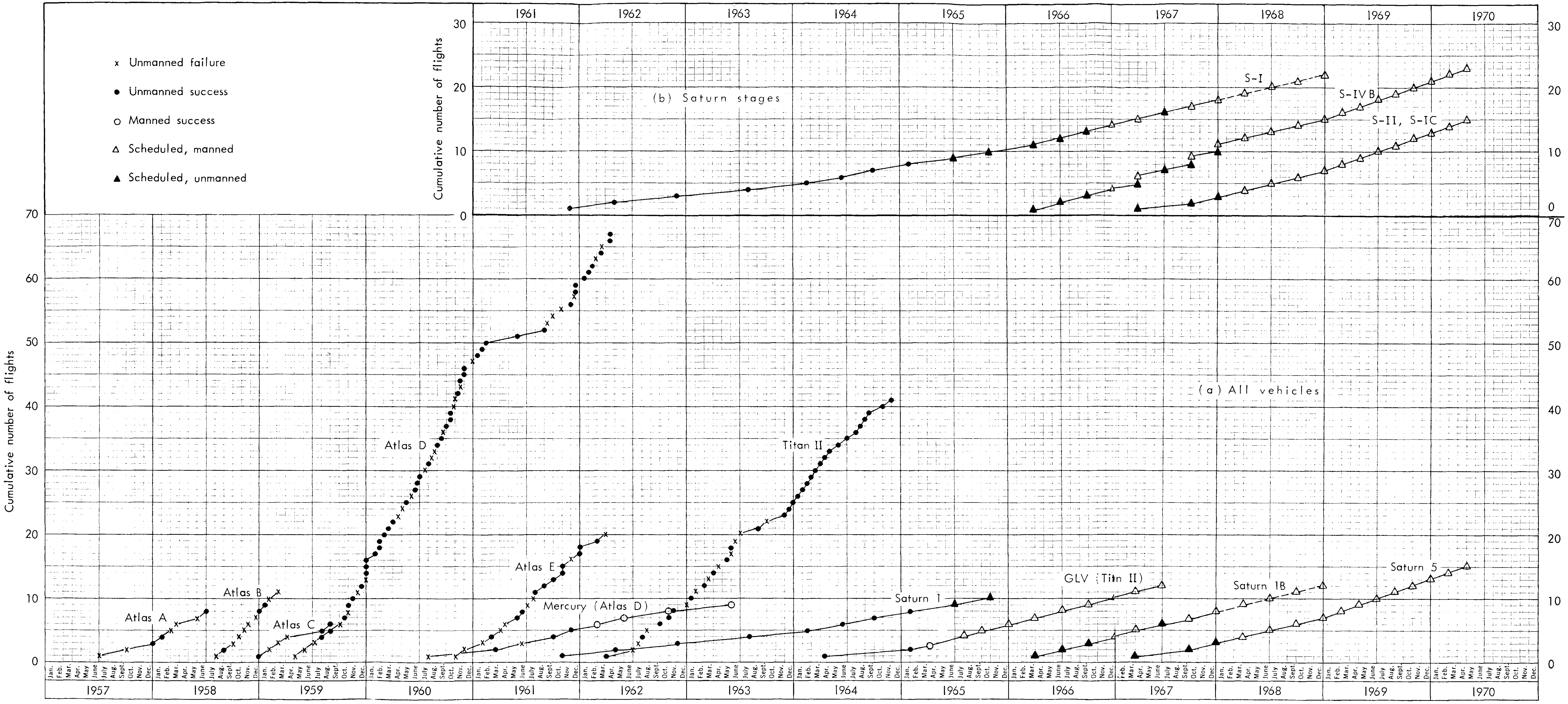

Fig. 1—Launch-vehicle flight-test history and plans for U.S. manned space-flight programs (25)

Table 1

SATURN BOOSTERS

Launch Vehicle	Payload[a] (lb)	Stage			Engine		
		No.	Designation	Thrust (thousands of lb)	No.	Type	Propellant[b]
Saturn 1	22,500	1	S-I	1600	8	H-1	LOX-RP
		2	S-IV	90	6	LR-10	LOX-LH
Saturn 1B	35,000	1	S-I	1600	8	H-1	LOX-RP
		2	S-IVB/1B	200	1	J-2	LOX-LH
Saturn 5	240,000	1	S-IC	7500	5	F-1	LOX-RP
		2	S-II	1000	5	J-2	LOX-LH
		3	S-IVB/5	200	1	J-2	LOX-LH

[a]For a 100-n-mi orbit. Saturn 1B and 5 also have the capability of carrying the 6600-lb launch escape system until it is jettisoned (equivalent to 2900 lb in 100-n-mi orbit).

[b]LOX Liquid oxygen
RP Hydrocarbon fuel
LH Liquid hydrogen

Table 2

SCHEDULED FLIGHT TESTS FOR SATURN 1B AND 5[a]

Vehicle	Scheduled Number of Flights	
	Prior to First Manned Mission	Prior to Last Manned Mission[b]
Saturn 1B	3	8
Stage 1 (S-I)	13	18
Stage 2 (S-IVB)	3	11
Saturn 5	3	10
Stage 1 (S-IC)	3	10
Stage 2 (S-II)	3	10
Stage 3 (S-IVB)	11	18

[a]See Fig. 1.

[b]While still meeting the 1970 lunar-landing goal.

of ten unmanned Saturn 5 flights could be made without sacrificing the 1970 target date. This number is indicated in Table 2, along with the associated individual stage flights. Table 2 also presents similar figures for Saturn 1B. Thus, Table 2 shows that Saturn 1B must be man-rated within three to eight flights and Saturn 5 within three to ten flights in order to accomplish the lunar landing before 1970.

While the Mercury program had six unmanned flights prior to the first manned flight, and the Gemini program proceeded with manned flights after only two unmanned launches, these programs were supported by a large number of missile flights (Table 3). For example, eight Atlas D flights were made in direct support of the manned Mercury program, and 63 missile flights contributed to the vehicle development before the first manned flight. In the case of Gemini, about 11 Titan II flights directly supported the manned program, and 40 missile flights contributed to the vehicle development. The significance of these supporting missile flights is the following: (1) Even though each of these programs employed thorough design and status reviews, special handling procedures, and a relatively low launch frequency (measures similar to those planned for Saturn 1B and Saturn 5), a relatively large number of flights (8 for Mercury and 11 for Gemini) were necessary before the launch vehicles were man-rated. (2) None of the flights were for vehicle development per se. (3) Each launch vehicle was composed of "select" components from a large supply of missile components. (4) The personnel were experienced with the vehicle design and the flight problems previously encountered.

The major difference between the flight-test program planned for Saturn 1B and Saturn 5 and the flight experience of Mercury and Gemini is in the number of flights scheduled for vehicle development. As indicated in Table 2, a maximum of only eight and ten vehicle-development flights are scheduled for Saturn 1B and Saturn 5, respectively, before 1970.

Since the Saturn 1B is a less sophisticated design than Saturn 5, and since the first stage of the Saturn 1B has already made eight successful flights in the Saturn 1 program, in the remainder of this Memorandum it is assumed that the Saturn 1B will be man-rated as scheduled.

Table 3

MISSILE-SUPPORT FLIGHTS

Purpose	Number of Flights: Mercury[4] (Atlas D)	Number of Flights: Gemini[5] (Titan II)
Direct support[a]		
Abort-system development	4	5
Reduction of roll rates	4	..
Reduction of vibration (pogo)	..	6
Vehicle development[b]	63	40

[a]In general, these experiments were flown piggy-back on missile flights having other flight objectives.

[b]Missile flights prior to first manned flight.

Although the Saturn 5 may experience difficulty in becoming man-rated on schedule, by accepting a lower reliability one might expect that it could place an unmanned payload into earth orbit significantly earlier than a manned payload (as will be demonstrated by the Apollo heat-shield tests). The contingency plan suggested may permit performance of the lunar mission on schedule in the event the man-rating schedule for Saturn 5 is found to be unattainable.

III. CURRENT CONTINGENCY PLANS

This section briefly discusses the Apollo flight mission assignments as they relate to the problem of contingency planning and describes and analyzes the contingency plans provided by the respective responsible NASA centers for the spacecraft and launch vehicle.

MISSION ASSIGNMENTS

The Saturn 1B and Saturn 5 test flights provide for launch-vehicle and spacecraft development and for demonstration of crew performance. Major program goals include (1) man-rating both Saturn 1B and Saturn 5 launch vehicles, (2) demonstrating the Command Module (CM) heat shield at earth orbit and lunar-return re-entry velocities, (3) transposition and docking of the Lunar Excursion Module (LEM), and (4) demonstration of 14-day crew and spacecraft capability. The NASA test philosophy requires that the entire launch vehicle (all stages) be flown on every launch. In essence, this "all-up" practice allows advantage to be taken of early first-stage successes by acquiring additional experience with the upper stages of the launch vehicle, thereby shortening the flight-test program.

The current flight mission assignments are shown in Table 4.[*] Of special interest are the following features: (1) The first lunar attempt is about one year before the 1970 target date; (2) two verification flights of the launch vehicle are required before men are committed; (3) the scheduled launch frequency is about three to four flights per year; (4) the earth-orbit testing phase of the spacecraft development can be essentially completed using the Saturn 1B; and (5) spacecraft test flights on Saturn 1B will be transferred to the Saturn 5 as soon as the Saturn 5 is man-rated.

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[*]These assignments were obtained from the Manned Spacecraft Center, Houston, Texas, in November 1964. Since these assignments were under review at the time, some modifications can be expected; however, due to the similarity between these assignments and those shown in Ref. 2, no major changes are anticipated.

Table 4

APOLLO FLIGHT MISSION ASSIGNMENTS

Calendar Year	Saturn 1B Flights		Saturn 5 Flights	
	No.	Mission	No.	Mission
1966				
First quarter	201	"Lob-type" trajectory for heat-shield development (velocity potential = 29,000 fps)	...	......
Second quarter	202	Same as 201	...	......
Third quarter	203	Liquid-hydrogen experiment for S-IVB childown	...	......
Fourth quarter	204	Manned earth-orbital flight using Block 1 CSM	...	......
1967				
First quarter	205	Same as 204	501	Heat-shield development using modified Block 1 CSM (velocity potential = 36,000 fps)
Second quarter	206	LEM only	...	......
Third quarter	207	Manned earth-orbital flight using Block 2 CSM & LEM	502	Same as 501
Fourth quarter	208	Same as 207	503	Same as 501 except using Block 2 CSM
1968				
First quarter	209[a]	Same as 207	504	Manned earth-orbital flight using Block 2 CSM & LEM[b]
Second quarter	210[a]	(c)	505	Manned circumlunar flight
Third quarter	211[a]	(c)	506	Manned lunar landing

[a]These flights are presently scheduled in case Saturn 5 experiences problems in becoming man-rated.

[b]Lunar-mission simulation.

[c]No mission assignments as [redacted]

SPACECRAFT

The current flight-test program provides for duplicate sequential spacecraft missions with the same objectives, while missions with interrelated objectives are separated, allowing use of previous flight results. Duplicate missions represent a contingency plan for an unexpected Saturn 1B failure, since NASA requires only one successful spacecraft-verification flight. This ground rule is based upon the feeling that there are only a few critical spacecraft failure modes that will necessitate aborting a mission after earth orbit has been reached.

The spacecraft contingency plan for development problems consists of (1) providing additional backup hardware, (2) separating the missions that have interrelated objectives (as mentioned above), and (3) providing dummy payloads to allow continued launch-vehicle development. Use of these dummy payloads is also planned in the event that Saturn 5 experiences major problems that postpone its availability. In this case spacecraft flight-testing is scheduled to continue using the Saturn 1B launch vehicle (see Table 4).

The contingency plan for handling the spacecraft weight-growth problem that has existed during the Apollo design phase consists only of improving the weight-control and reporting procedures and maintaining an unallocated weight margin of about two percent. Unfortunately, the consequences of Apollo spacecraft weight growth are more severe and more difficult to handle than in the case of Mercury or Gemini spacecraft. For example, an increase in the inert weight of the Apollo spacecraft requires increases in propulsion-systems weights and propellant weights, which compounds the payload-weight increases for the launch vehicle; whereas only the launch-vehicle payload requirements were affected by the spacecraft weight growth of Mercury and Gemini. As discussed on pp. 28 - 32, the earth-orbit-rendezvous plan suggested in this Memorandum offers an alternative solution to the Apollo weight-growth problem.

LAUNCH VEHICLE

The current NASA contingency plans for the launch vehicle call for (1) additional backup hardware to support the program, and (2) a booster-uprating plan to handle future spacecraft weight growth. Even with these contingency plans, both the spacecraft and the Saturn 5 launch vehicle must still be man-rated before a lunar landing can be attempted. In order to avoid having to man-rate the Saturn 5, the contingency plan considered in Section IV is based on (1) the probability that more unmanned Saturn 5 launches will be required for man-rating than are presently planned; (2) the capability of Saturn 5 to place a fully loaded Apollo spacecraft into earth orbit before it is man-rated; and (3) the completion of earth-orbit development of the Apollo spacecraft as presently planned, i.e., essentially independent of Saturn 5. There are only two experiments presently planned that require the use of the Saturn 5 launch vehicle for spacecraft development: the high-speed (36,000 fps) re-entry heat-shield tests and the lunar-mission simulation (see 501 through 504 in Table 4). The heat-shield-experiment flights are unmanned (three Saturn 5 flights allowed), while the simulation experiment is not clearly defined yet and may be eliminated from the program. Hence, the spacecraft development could be completed with three or four Saturn 5 flights,* and the Apollo spacecraft may be ready for translunar missions before the Saturn 5 is man-rated. If so, then the man-rating of Saturn 5 would become the pacing item in the Apollo program.

Other situations may occur that would cause lengthy delays in spacecraft development and a postponement of translunar missions. Such situations may develop with or independent of a Saturn 5 man-rating problem. Although these are interesting areas of investigation for contingency planning, this Memorandum examines only the case where the Apollo spacecraft development is completed prior to man-rating Saturn 5.

The options presently available for minimizing delays in man-rating the Saturn 5 might be an increase in the engineering effort to assist in correcting the problems or to assume a higher-risk program; for example, dispensing with the two verification flights for the launch vehicle prior to man-rating and relying more heavily on the launch escape system. Assuming that the engineering effort will be applied as

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*With NASA's ground rules it is conceivable that only one Saturn 5 flight would be required for spacecraft development (heat-shield reentry test).

necessary (as was done in the case of Mercury and Gemini), then a significant change in the length of the Saturn 5 flight-test program probably cannot be expected from increasing the engineering effort. Hence it appears that an increase in the risk level may be the only option to accelerate the program. The results this option might have are, however, uncertain. For example, if a manned flight failed immediately after a decision to eliminate, say, the launch-vehicle verification flights, the entire Apollo program might be jeopardized.

Extending the Apollo program would also be financially costly; each additional Saturn 5 launching would cost about $150 million (not including payload), and each additional month of development would cost from $100 to $200 million. Thus, the 1- to 1½-year slippage available in the present program, while still allowing a moon landing by 1970, could cost approximately $2 billion more than if the lunar landing is made as presently scheduled. Hence, one of the objectives of the contingency plan discussed in Section IV is to provide an alternative mode of attaining the scheduled lunar-flight date that would entail only a small incremental cost if this alternative is not employed. In fact, a savings of both time and dollars could be obtained by using the suggested contingency plan even in the event that only one or two additional unmanned Saturn 5 flights are required. The time saved may be relatively small, i.e., three or four months per flight, if the scheduled Saturn 5 launch frequency is realized; however, if the launch frequency is lower than anticipated, particularly during the early phase of the flight-test program, then the program time saved might be appreciable.

IV. AN ALTERNATIVE CONTINGENCY PLAN: EARTH-ORBIT RENDEZVOUS

It is recognized that accomplishing the Apollo program as presently planned, that is, manning the Saturn 5 on its fourth flight and making the lunar attempt on the sixth flight, would probably result in the earliest and lowest-cost lunar landing. It is assumed here, however, that the Apollo spacecraft development is accomplished as planned, but that the Saturn 5 launch vehicle experiences minor problems (e.g., during open-loop testing of abort sensing system) that do not affect its capability of placing the fully loaded spacecraft into orbit but do require modifications and flight verifications, thus postponing man-rating the Saturn 5.

As discussed in Section III, under the present NASA program the Apollo spacecraft flight tests would be continued using Saturn 1B, and the lunar-landing mission would be postponed until Saturn 5 is man-rated. We suggest here an alternative contingency plan that would utilize an earth-orbit-rendezvous mode of operation to place the astronauts in the Apollo spacecraft. This concept consists of launching an unmanned spacecraft via a Saturn 5 launch vehicle that is not yet man-rated and then, given a successful launch, sending the astronauts to the orbiting spacecraft via a man-rated launch vehicle.[*] This concept is not new,[**] but most studies of the earth-orbit-rendezvous mode of operation require either spacecraft assembly or refueling in earth orbit to complete the mission.[6] These approaches generally attempt to utilize the entire payload placed in earth orbit, which need not be a requirement when considering a contingency plan. Hence, in the basic approach described in this Memorandum the payload of the ferry vehicle will be left in earth orbit after the astronauts transfer to the Apollo spacecraft.

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[*] The reverse sequence could be used.

[**] For example, the so-called EOR mode of operation was considered and discarded as a plan for the Apollo program. This Memorandum does not suggest reopening that issue nor diverging significantly from current Apollo hardware approaches.

In order for this contingency plan to be attractive it should provide

1. The option of delaying the decision for implementation of the plan until as late as possible, preferably until after the first Saturn 5 flight
2. The provision for continued use during subsequent lunar landings if necessary
3. A minimum impact on the present Apollo design and program schedule
4. A relatively low initial-investment cost

In addition to these desirable (though not strictly necessary) features, the earth-orbit-rendezvous mode of operation requires a man-rated launch vehicle and a spacecraft with demonstrated re-entry capability, sufficient velocity potential for rendezvous, and docking compatibility with an Apollo CM. New vehicles could be designed and developed to fulfill these requirements, but because low cost is desirable, only existing or presently scheduled spacecraft and launch vehicles will be considered in this Memorandum; specifically, the Gemini spacecraft/Gemini Launch Vehicle (GLV) and the Apollo Command and Service Modules (CSM)/Saturn 1B. Alternative systems that use other boosters (e.g., Titan IIIC, Saturn 1, or Atlas-Centaur) with these spacecraft will not be considered because extensive modifications would be required to mate the launch vehicle and spacecraft, hence increasing the lead time as well as the cost of the contingency plan. In addition, flight-testing the combination would probably be necessary.

In performing the earth-orbit rendezvous for manning the Apollo spacecraft, either the spacecraft or the ferry vehicle could be placed into orbit first. These two alternatives will be discussed in this section with respect to the crew and spacecraft limitations.

FERRY VEHICLES

The present Gemini schedule (Table 5) indicates that by mid-1968 (date of the first Apollo translunar mission) about 12 earth-orbit flights will have been accomplished in the Gemini program. Of these

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Table 5

GEMINI LAUNCH SCHEDULE

Type of Test	Year				Total
	1964	1965	1966	1967	
Vehicle verification and re-entry experiments	1	1	0	0	2
Manned flights					
Rendezvous	0	1	4	2	7
Nonrendezvous	0	3	0	0	3

flights, ten are to be manned, with rendezvous being accomplished on seven. The rendezvous missions use the Agena stage as the target vehicle, with the Gemini spacecraft providing the rendezvous velocity potential. In addition to the objective of developing rendezvous techniques for Apollo, the Gemini program will also provide data concerning the effects of long-term (14 days) weightlessness on the astronaut's performance. Hence, the Gemini spacecraft/GLV could be used as the ferry vehicle for the Apollo contingency plan suggested here, although many limitations exist which will minimize its effectiveness in this mode of operation. For example, the Gemini spacecraft is presently designed for only two astronauts, whereas three are required for the Apollo translunar missions. Although it may be feasible to redesign the spacecraft for three men, considerable design effort would be necessary to stay within the payload capability of the Gemini booster, Titan II. A contingency-plan application probably would not justify this redesign effort; however, should the Gemini spacecraft/GLV be uprated to three men for another application (e.g., Manned Orbital Laboratory) before 1968, then it could be utilized as a ferry vehicle for Apollo. Other design and operational features of the current Gemini spacecraft/GLV that limit its use in a ferry-vehicle mode should also be examined during the redesign phase. Some of the more obvious limitations are (1) a different space-suit design than that for Apollo; (2) the necessity to expand the crew-training program for each mission to include the operation of the Gemini and Apollo spacecraft; (3) relatively small velocity potential for rendezvous, and thus greater

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sensitivity to launch errors;* and (4) a different docking and crew-transfer design than that for Apollo.

The other ferry vehicle to be considered for the earth-orbit rendezvous mode is the Saturn 1B with the Apollo CSM as its payload. This is the same basic configuration that is used during early earth-orbit development in the Apollo program. Features of the Saturn 1B/CSM and Gemini spacecraft/GLV systems that are relevant to a ferry-vehicle application for the rendezvous mode are compared in Table 6. The Saturn 1B/CSM flight plans are relatively limited--four manned flights as compared with ten for Gemini spacecraft/GLV--but the Saturn 1B/CSM provides the three-man-crew capability necessary for the contingency plan suggested in this Memorandum. The other major disadvantage of Saturn 1B is that the use of cryogenic propellants makes it somewhat more difficult to launch on time because of propellant conditioning; however, the previous eight flights should provide sufficient experience to manage this problem. It should be noted, however, that a precise on-time launch capability for the mission described in this Memorandum is necessary for only the rendezvousing vehicle. Whether this is the Saturn 1B or Saturn 5 depends upon the sequencing, which is discussed below. As indicated in Table 6, the velocity potential

Table 6

COMPARISON OF GEMINI SPACECRAFT/GLV AND SATURN 1B/CSM

Item	Gemini Spacecraft/GLV	Saturn 1B/CSM
Flights planned[a]		
Unmanned	2	4
Manned		
Rendezvous	7	0
Nonrendezvous	3	4
Velocity potential[b] (fps)	650	5000
Crew Size	2	3

[a]To be completed by the end of 1967.
[b]For rendezvous.

Gemini spacecraft has the capability of making only a 0.53-deg change in the orbit inclin[redacted] of the CSM available for the rendezvous operation is about 5000 fps. This velocity potential is achieved by using the partly loaded SM and its propulsion system. The spacecraft maneuvering capability provided by this velocity potential will substantially reduce the sensitivity of the rendezvous operation to launch errors, as discussed later.

The present Apollo schedule includes 12 Saturn 1B launch vehicles; four of these will be available for alternate missions, providing the Saturn 5 is man-rated after three flights. As indicated earlier, these additional Saturn 1B's are to be used for continued spacecraft flight-testing in earth orbit if the Saturn 5 experiences man-rating problems, so these vehicles will also be available for dual launches with Saturn 5. Since backup CSM's are also scheduled, it appears that major modifications to the present Apollo schedule would not be necessary to support this contingency plan. In addition, the spacecraft-production capability of eight per year is sufficient to support four dual launches per year, which should be more than adequate for the initial phase of the Apollo mission.

SEQUENCING CONSIDERATIONS

Based upon the previous discussion, it appears that the ferry vehicle preferred for this contingency plan is the Saturn 1B/CSM; hence two cryogenic vehicles must be launched in series in order to accomplish the lunar-landing mission. Some of the sequencing considerations involved in determining the preferred approach, practicality, and attendant hardware lead times are presented here. No attempt is made to perform a mission analysis for earth-orbit rendezvous; only major considerations will be highlighted. One of these is the additional length of time required in earth orbit to accomplish the rendezvous operation. This consideration affects both the length of the astronauts' mission as well as the duty cycle of the spacecraft.

To measure the astronauts' capability for a seven- to nine-day lunar mission, 14-day earth-orbit missions are scheduled in the Gemini and Apollo programs. The effects of long-term weightlessness and other orbital space-flight stresses should be established in these long

*Service Module.

missions; thus a limited extension in the length of the Apollo astronauts' mission does not appear to be critical.

The 14-day earth-orbit missions in the Apollo program will also demonstrate the spacecraft's (CSM and LEM) long-endurance capability. During the normal earth-orbit phase of the Apollo lunar mission the S-IVB stage of the Saturn 5 launch vehicle remains attached to the Apollo spacecraft to provide the subsequent translunar injection. The nominal Apollo mission requires that the S-IVB remain in earth orbit up to a maximum of 4½ hr, after which time the degradation in stage performance (mainly from loss of propellants (LOX-LH) due to boil-off (700 lb/hr) and expenditure of the attitude-control propellants) is sufficient to prevent translunar injection. Since Saturn 5 would be unmanned in the mode of operation discussed in this Memorandum, a 2900-lb payload increase* could be obtained by eliminating the launch escape system. This represents a direct increase in S-IVB propellants in orbit and thus allows an increase of about 4 hr in the earth-orbit stay time of the S-IVB stage.** To stretch the earth-orbit capability of the S-IVB stage much beyond 10 hr will probably necessitate a redesign of the common bulkhead to prevent freezing of the liquid oxygen. Other areas in the S-IVB design may be more time-critical than the common bulkhead. A detailed review of the stage design is not within the scope of this study, but one would be required before undertaking the contingency plan suggested here.

Long-term earth-orbit storage capability for the S-IVB may be desirable for other applications, such as the Apollo Extension Support. If so, then the stage would have to be modified to incorporate such items as superinsulation, reducing the boil-off to about 160 lb/hr; a new common bulkhead between the propellant tanks; and perhaps a new attitude-control system. Because these modifications require about

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*See Table 1.

**Further increases in the S-IVB stay time would necessitate increasing its propellant load or using some of the reserve propellant.[8] For example, to extend the total stay time to 9 hr (six orbits) requires an additional 300 lb of propellant (about 0.1 percent of the total propellant load). It is doubtful that a structural modification would be necessary for this minor propellant increase.

$20 million and about three years to design and develop, they are not considered to be justified by this contingency plan, hence the maximum earth-orbit stay time considered here for the S-IVB stage is approximately 10 hr.

Another important sequencing consideration is the timing relationship between the earth-orbit launch window, the launch-vehicle countdown, and the translunar launch window. The current Apollo mission also deals with these elements; however, the earth-orbit-rendezvous mode suggested here requires the target vehicle to be launched sufficiently in advance to allow the rendezvous operation to be accomplished before the opening of the translunar launch window. There are many ways in which the rendezvous mission can be accomplished, and one objective of the Gemini program is to evaluate several rendezvous approaches.[7] While it is premature to recommend a technique at this time, pending the Gemini results it appears that the various approaches for earth-orbit rendezvous will not severely affect the Apollo hardware requirements. Although the selection of the final rendezvous approach for Apollo can be postponed, it is interesting to consider here some of the basic elements of the rendezvous operation that determine the feasibility of applying it to the Apollo program and the limitations of its use in the program.

The earth-orbit-rendezvous concept requires nearly simultaneous countdowns of Saturn 1B and Saturn 5 launch vehicles, and there appears to be no physical constraint to prevent this mode of operation at Cape Kennedy. For example, separate launch complexes (37 and 39), crews, and propellant reserves will be available to support individual operations.

Launching the target vehicle with an orbit-plane inclination greater than the latitude of Cape Kennedy allows daily rendezvous opportunities; more importantly, rendezvous opportunities exist during several subsequent orbits of the target vehicle following its launch. For example, by using a parallel-plane, variable-azimuth launch technique for the chase vehicle in combination with the plane-change capability of the manned vehicle (about 10 deg*), rendezvous opportunities occur during

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*This is comparable to the plane-change capability of the Agena stage, which is the Gemini target vehicle; therefore, this rendezvous operation could be investigated prior to attempting it on Apollo.

the first three or four orbits of the target vehicle. These opportunities will obviously be limited by such considerations as range-safety limits on launch azimuths (72 to 108 deg at Cape Kennedy) and landing-area restraints. However, the landing- or recovery-area restraint only applies if the manned ferry vehicle is launched second.

The target vehicle will be in a position for a direct rendezvous only for an instant on each rendezvous-compatible orbit--hence the necessity for a launch-on-time (within a few minutes) capability for the chase vehicle. Since neither Saturn 1B nor Saturn 5 has been launched, countdown procedures have not been finalized. However, eight Saturn 1 launches have been successful, and, because of the similarity between the Saturn vehicles, it is reasonable to expect that the Saturn 1 countdown experience will be illustrative of that for Saturn 1B and Saturn 5. Although the timing of the several Saturn 1 countdowns differed in detail, no launch-on-time requirement existed; thus, in order to maximize the chance of a successful launch, necessary vehicle or range changes were made and the concomitant countdown holds were tolerated.

In general, one crew has been used for the entire countdown, which is normally divided into two parts. The first part is scheduled to begin around midnight of the day before the launch and runs from T - 1035 to T - 545 min. During this time interval certain preparatory actions are taken, such as checks of the propulsion systems, some ordnance installations, and tests of tank moisture content. A hold is then scheduled to allow the crew to rest, and the second part of the countdown begins around midnight of the day of the launch, and runs from T - 545 to T - 0 min, launch. During the second part of the countdown the booster is prepared for launch, ground systems and vehicle checkouts are made, fueling is done, and the launch is attempted.

In some cases other scheduled holds are included in the countdown sequence to provide for ground-equipment operation, simple remedial actions, and review of system and countdown status; however, during all of the Saturn 1 launches events have occurred that have caused additional holds, thus lengthening the actual countdowns. Table 7, which summarizes the relevant Saturn 1 countdown events, shows that holds of

Table 7

SATURN 1 COUNTDOWN SUMMARY(9-14)

Flight Number	Date of Launch	Holds: Cause	Holds: Time (min)	Holds: Length (min)	Holds: Total (min)	Scheduled Countdown Duration
SA-1	10/27/61	Cloud Cover	T - 120	34	66	10 hr
		Bad weather	T - 20	32		
SA-2	4/25/62	Ship interference	T - 10	30	30	10 hr
SA-3	11/16/62	Power failure of ground generator	T - 75	45	45	10 hr
SA-4[a]	....	.....	...	..	..	.....
SA-5	1/27/64	Network checks	T - 550	3	..	.....
		Battery verification	T - 530	17		
		Change accelerometer	T - 430	27		
		Clear pad for LOX loading	T - 280	20		
		LOX leak, causing launch to be cancelled	T - 250	48		
	1/29/64	Scheduled hold	T - 30	20	93[b]	10 hr, 40 min
		RF interference on C-band radar	T - 13	73		
SA-6[c]	5/28/64	ST-124 stabilizer azimuth alignment	T - 85	38	174[d]	9 hr, 5 min
		Adjust S-I LOX-replenish ANNIN valve	T - 70	60		
		S-IV LOX pump temperature	T - 4	1		
		LOX vapor broke; theodolite beam	T - 41[e]	75		
SA-7	9/18/64	Accidental FIREX system activation on service structure	T - 245	69	162[f]	9 hr, 5 min
		Scheduled hold	T - 30	20		
		S-IV LOX pressurizing indicated malfunction	T - 30	4		
		Investigate S-I hydraulic-pump temperature	T - 12	20		
		Grand Turk radar intermittent	T - 5	49		

[a]No information available at time of publication.

[b]Plus 12 min lost due to recycle.

[c]A first launch attempt on 5/26/64 was canceled at T - 115 min due to a compressor-motor failure in the IU section.

[d]Plus 15 min lost due to recycle.

[e]T - 41 sec, not min.

[f]Plus 8 min lost due to recycle.

from 30 min to over 3 hr were experienced. Although these holds caused launch-time delays, all launches were successful. Thus, it seems possible to extend the countdown to allow enough time to correct the majority of the kinds of problems experienced with the Saturn 1 boosters. Assuming the Saturn 1 experience is indicative of what will occur during Saturn 1B and Saturn 5 launches, and recognizing the increased complexity of the latter vehicles, perhaps the countdown should be started 4 to 5 hr earlier as an allowance for correcting unexpected problems. Of course, major problems will occasionally develop where the 5-hr allowance would be inadequate. For example, any problem whose correction requires defueling the launch vehicle falls into this category.

Although it seems reasonable to conclude that, except for major countdown problems, both the Saturn 1B and Saturn 5 could be launched on time, minor errors in lift-off time (a few minutes) may occur. In such cases, techniques are available that will compensate for the phasing error, e.g., a "dog-leg" maneuver during the powered flight of the launch vehicle, or a "catch-up" maneuver after earth-orbit is achieved.[6] The velocity potential of the ferry vehicle can be used for the catch-up maneuver; that is, if one-half the available velocity potential (2500 fps) is used, then a 2-min launch error could be corrected within about 30 min (one-third of an orbit). Selection of the optimum maneuver to compensate for launch-time errors is not within the scope of this study; but these errors, i.e., orbit-plane and phasing, would have to be canceled as quickly as possible, preferably within one orbit, in order to preserve the S-IVB performance capability.

The time required for rendezvous, docking, and crew-transfer operations should also be minimized. If more than one or two orbits are required for these operations, the S-IVB coasting capability might have to be increased. However, it is felt that these operations can be accomplished within this time limit, particularly if the rendezvous and docking phases are demonstrated during the Gemini program.

In order to accomplish the docking and crew-transfer phases of the earth-orbit rendezvous mission, the CM, which is carried aloft by the ferry vehicle, must be modified. While the details of this modification have not been examined, the initial thought is that a coupling similar to the LEM drogue (Fig. 2) could be designed to fit on the CM. It is desirable to hold the lead time for such modifications to about one year, which seems reasonable, because, for example, no special flight tests would be necessary. If so, then the decision to undertake an earth-orbit-rendezvous contingency plan for Apollo can be postponed until after the initial Saturn 5 launch. This allows an assessment of the status of both the launch vehicle and spacecraft during a late stage of development before implementing this contingency plan.

Several alternative situations must be considered when assessing whether the men or spacecraft should be placed into earth orbit first. For example, one can argue that the men should not be committed until after the Saturn 5, which has a greater launch risk than Saturn 1B, has placed the Apollo spacecraft into earth orbit. This approach allows one to determine the condition of the spacecraft prior to committing the astronauts. If the Saturn 5 fails to place the payload into orbit, then the Saturn 1B ferry vehicle can be either assigned to an earth-orbit mission or held until another Saturn 5 becomes available. As indicated in Section III, the current Apollo schedule includes the continued flight-testing of the spacecraft in earth orbit using the Saturn 1B as the launch vehicle; thus the reassignment of the Saturn 1B is consistent with NASA's current policy. However, it appears that the manned ferry vehicle could be placed into orbit with primary and secondary objectives. The primary objective would be a rendezvous with an Apollo spacecraft for a translunar mission, and the secondary objective would be continued earth-orbit flight-testing of the Apollo spacecraft if Saturn 5 fails to place its payload into orbit on schedule. Although the timing of the second launch is more critical than the first, the additional launch restrictions placed upon a manned launch (e.g., recovery-area restraints) suggests that a decision as to which vehicle should be launched first, Saturn 1B or Saturn 5, cannot be made based on timing considerations without additional study.

From the standpoint of hardware limitations, it appears that unless the S-IVB stage[*] is redesigned to allow for long-term storage in orbit, it will be desirable to minimize the time the S-IVB stays in

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[*] The S-IVB attached to the Apollo spacecraft that will be used for the lunar-landing mission.

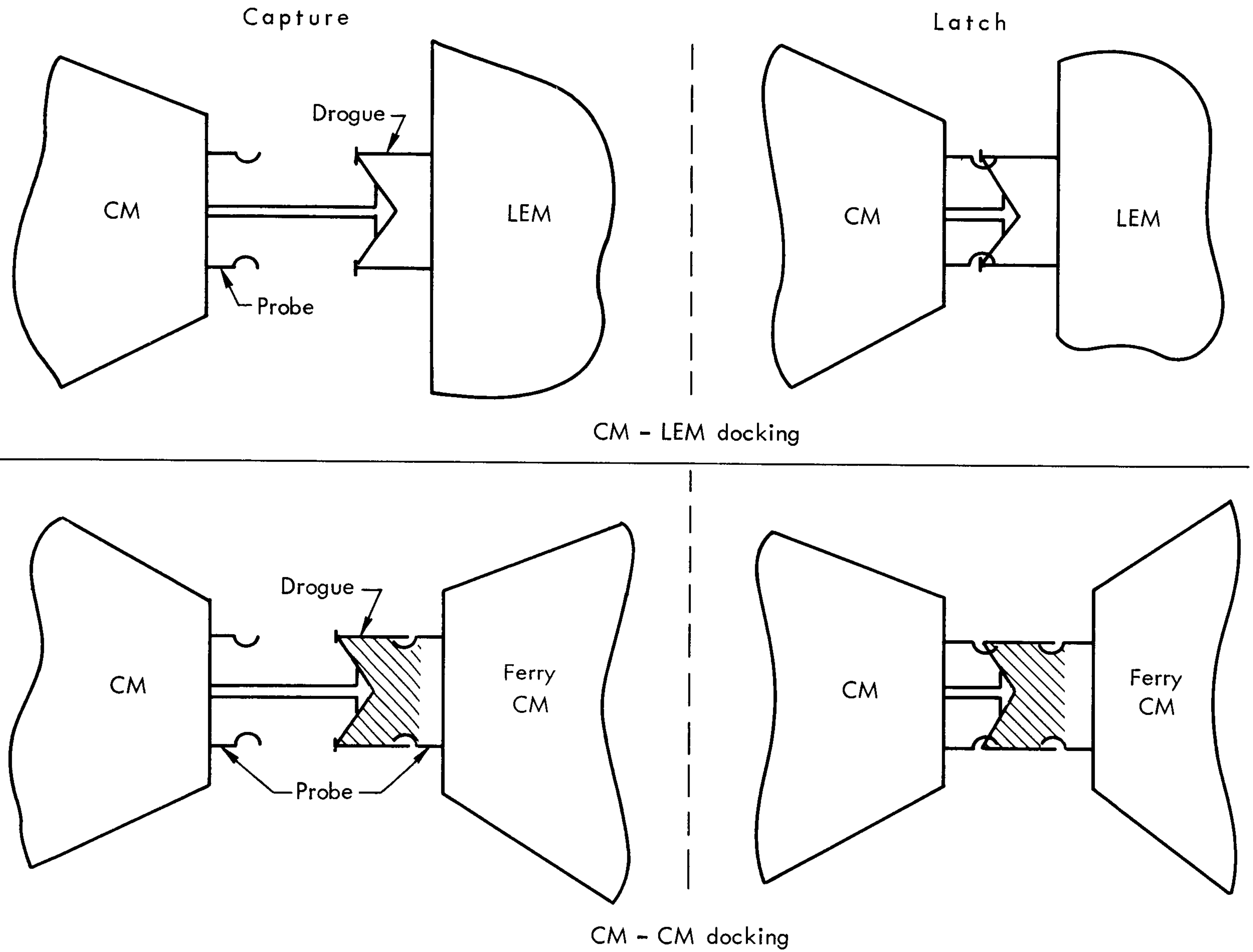

Fig. 2—Schematic comparison of docking techniques for the Apollo Mission and earth-orbit rendezvous

earth orbit. Although this is accomplished by launching the Apollo spacecraft via a Saturn 5 after the ferry vehicle is in orbit, the feasibility of accomplishing the mission discussed in this Memorandum within the S-IVB operating limits needs to be studied further in order to determine if there are other time-critical areas that are more important than those highlighted in this Memorandum.

Another consideration affecting the sequencing decision for earth-orbit rendezvous is the crew stress. The launch concept described in this section will undoubtedly increase the duration of the first time-critical period for the astronauts on operational missions. For example, this period is presently about 8 hr long; during this time the astronauts monitor the spacecraft systems during launch, take navigational sightings, realign the inertial measurement units, and check out the spacecraft during earth orbit, and then transpose the LEM after translunar injection.[15] About a 4- or 5-hr increase in this time-critical period could be expected for the nearly simultaneous launch and rendezvous operations. This represents an increase in the peak stress level for the crew, but this can be compensated for by allowing part of the crew to rest during nontask periods. An alternative approach would be to place the crew into earth orbit a day or two before the rendezvous operation. Although this approach lengthens the mission for the astronauts, it would still be less than the 14-day capability previously demonstrated and would allow (1) a reduction in the duration of the initial time-critical period for the astronauts, (2) the crew to become preconditioned prior to translunar injection, and (3) termination of the mission should a crew member fail to perform as expected.

In summary, extending the length of the Apollo mission to allow for an earth-orbit rendezvous does not appear to be unreasonable in view of the expected 14-day capability of the astronauts and spacecraft. The earth-orbit stay time of the S-IVB stage appears to be critical, in that its present capability is only 4½ hr and its maximum life (without major redesign) may only be 10 hr. Elimination of the lunar escape system on the unmanned Saturn 5 launch would increase the S-IVB stay time by about 4 hr. Subject to detailed mission analysis, it appears that (1) the correction velocity provided by the ferry CSM is sufficient to minimize launch timing and phasing errors, (2) the use of scheduled holds during countdown can allow an on-time launch capability for Saturn 1B and Saturn 5, and (3) sufficient time is available to allow for earth-orbit rendezvous with current Apollo hardware. The only hardware modification is a LEM-type drogue for the ferry CM to allow docking of the two CM's. Lead time for such a modification is about one year. The sequencing of the astronauts and lunar spacecraft into earth orbit is unresolved; both alternatives appear feasible.

COST IMPLICATIONS

As mentioned earlier, a desirable feature for a contingency plan is that the initial investment should be relatively low so as to minimize the expenditure in case it becomes unnecessary to employ the contingency plan. On the other hand, if it becomes necessary to use a contingency plan, this should result in a minimum delay in accomplishing the program objective. Indicated below is a crude preliminary estimate of the possible impact on the Apollo program cost of further consideration of the earth-orbit-rendezvous contingency plan.

Initially, an R&D expenditure will be associated with obtaining the technical data necessary to permit a decision to undertake the contingency plan should Saturn 5 experience man-rating problems. This cost would cover such items as a detailed mission analysis, a study of simultaneous countdown procedures, a design review of the earth-orbit stay-time limitation of the S-IVB stage, and a design study of techniques for docking two CM's. Although these items have not been costed, it is anticipated that only a relatively small expenditure would be necessary, perhaps several million dollars.

In addition to this expenditure significant changes in program resource allocation must be considered. First, the schedules for launch vehicle and spacecraft delivery currently programmed during 1968 and 1969 are not sufficient to support four earth-orbit crew-transfer attempts per year.* Thus, the decision to implement the earth-orbit

*This launch frequency is used only for illustrative purposes. The actual launch frequency would depend upon a detailed study of the mission analysis and dual-launch approach.

crew-transfer contingency plan would necessitate an allocation of additional funds and rescheduling of the presently committed launch vehicles and spacecraft during 1968 and 1969. As noted in Table 8, the estimated additional resources required are about $250 million during 1968 (for three CSM's) and $370 million during 1969 (for four Saturn 1B's and two CSM's). Although this represents about a 17 percent increase in the total hardware allocation for this period, an excess of LEM's and Saturn 5's would exist should it become necessary to use this contingency plan for the entire period. This represents an unlikely event, since Saturn 5 would probably be man-rated during this period, thereby eliminating the need for the earth-orbit crew-transfer operation during subsequent flights.

Table 8

RESOURCES REQUIRED FOR PROGRAMS

Item	1968		1969	
	Present Apollo Program	Earth-Orbit-Rendezvous Contingency Plan[a]	Present Apollo Program	Earth-Orbit-Rendezvous Contingency Plan[a]
Saturn 1B	4	4	0	4[c]
Saturn 5	4	4	6	4
CSM	5	8[b]	6	8[c]
LEM	5	4	6	4

[a] Assuming four crew-transfer attempts per year.

[b] Additional hardware and launch costs for three CSM's are about $250 million.

[c] Additional hardware and launch costs for the two CSM's and four Saturn 1B's total $370 million.

Second, if it were decided to use the earth-orbit crew-transfer mode of operation, an incremental operating cost would be incurred. It seems appropriate to compare this with similar costs associated with the current approach, which provides for both continued launching of Saturn 1B's for spacecraft development (using CSM's only) and continuation of the Saturn 5 [redacted] until it is man-rated.

If the Saturn 5 were not yet man-rated, flights subsequent to 503 (see Table 4 in Section III) probably would not include the fully equipped Apollo spacecraft necessary for the earth-orbit-rendezvous contingency plan. Thus, the contingency plan would require an Apollo spacecraft (CSM, LEM, and an additional drogue) at an operation cost of about \$135 million for each earth-orbit-rendezvous attempt.[16] If the crew-transfer attempt were unsuccessful, this figure would represent the increased program cost (per attempt) beyond that of the current approach of continuing the Saturn 5 flight-test program until it is man-rated. If, on the other hand, the crew-transfer attempt is successful, then at least one less Saturn 5 flight would be required, at a saving of \$150 million, and the lunar landing could be made at least three months earlier than with the current Apollo contingency plan, thereby reducing further the NASA manned space program cost attributable to the Apollo program.

A detailed cost analysis would have to consider a range of additional unmanned Saturn 5 flights for man-rating and to bracket reasonable probabilities of success for earth-orbit crew transfer (including the probability of launch-vehicle success). To illustrate this, the estimated reduction in the program cost[*] to the first lunar landing is plotted in Fig. 3 against the number of Saturn 5 launches necessary for man-rating. The curves indicate the cost difference for 100, 75, and 50 percent success of the alternative contingency plan assuming perfect Apollo mission success after man-rating Saturn 5. On each curve the circled points designate the Saturn 5 launch (unmanned) on which the lunar landing is accomplished, i.e., when three successful crew transfers are accomplished. For example, if Saturn 5 were to encounter man-rating problems requiring three additional unmanned launches (making a total of six), then the cost of the first lunar landing using the alternative contingency plan (assuming 100 percent

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[*] The cost reduction shown in Fig. 3 is calculated by subtracting the cost of the first lunar landing achieved with the earth-orbit crew-transfer mode of operation from the cost of accomplishing the same landing with the current contingency plan, delaying the lunar landing until the Saturn 5 is man-rated. These costs account for differences in launch vehicles and spacecraft launched, and in program operating expenditures.

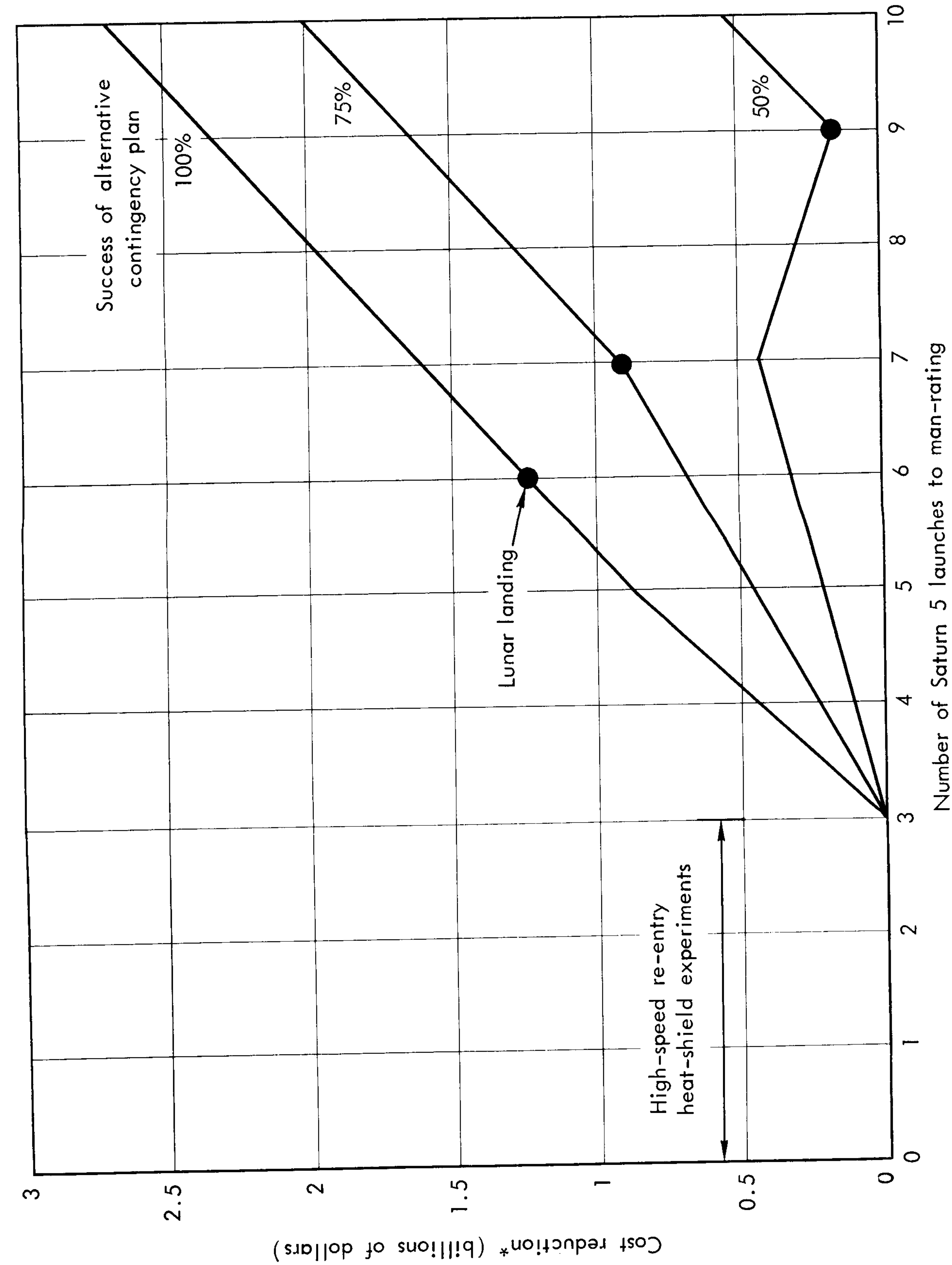

Fig. 3—Cost implications of alternative contingency plan (to first lunar landing)

*(See p.27)

success) would be about $1.2 billion less than if the lunar landing were delayed until the Saturn 5 is man-rated and then the landing program continued as planned. Another interpretation of this cost reduction or "savings" is that use of the alternative contingency plan could increase by about $1.2 billion the resources (i.e., launch vehicles, spacecraft, etc.) not used by the Apollo program and therefore available for transfer to other advanced manned missions, e.g., subsequent lunar landings.

To illustrate the hardware requirements and program duration for the above example, a comparison is made in Table 9 between the present Apollo program, with and without a man-rating problem, and the earth-orbit-rendezvous contingency plan, with and without a failure during one of the crew-transfer attempts. If as in Situation 2 (Table 9) three unmanned Saturn 5 flights were to be required for man-rating the Saturn 5, the date of the first lunar landing would be delayed about seven to nine months and the cost of the additional spacecraft and launch vehicles would be about $850 million.* On the other hand, the use of the earth-orbit-rendezvous contingency plan would provide the possibility of maintaining the present scheduled lunar-landing date, provided that all of the crew-transfer attempts were successful (Situation 3). Furthermore, the associated cost of the additional CSM's and Saturn 1B launch vehicles would be about $400 million. However, if one of the crew-transfer attempts were unsuccessful (Situation 4), the lunar landing could still be made four to six months earlier and at a lower incremental cost than by continuing the unmanned Saturn 5 flight tests until it is man-rated (i.e., Situation 2). Incremental costs shown in Table 9 do not include the effect of changes in program duration on operating costs not directly associated with launch vehicles and spacecraft. During 1968 the expenditure rate of the Apollo program is expected to be about $100 million per month. Adding this expenditure to the hardware costs of Situations 2 and 3 in Table 9 and computing the difference, one obtains (approximately) the $1.2 billion reduction in cost for the first lunar landing previously discussed.

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*In each case the Apollo missions are considered completely successful following man-rating of Saturn 5.

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Table 9

APOLLO HARDWARE REQUIREMENTS AND PROGRAM DURATION
(Period after third Saturn 5 flight to first lunar landing)

Program and Assumed Situation	Hardware Requirement				Duration (months)	Lunar Landing Saturn 5 Flight Number	Increase in	
	Saturn 5	Saturn 1B	CSM	LEM			Hardware Cost[a] (millions of dollars)	Program Duration (months)
1. Present program assuming no man-rating problem	3	0	3	3	9	506[b]	...	...
2. Present program assuming a man-rating problem	6[c]	3[d]	6	3	16 - 18[e]	509	855	7 - 9[e]
3. Earth-orbit-rendezvous contingency plan with no failures	3	3	6	3	9	506	405[f]	0
4. Earth-orbit-rendezvous contingency plan with one failure	4	3	7	4	12	507	690[f]	3

[a] Includes those operating costs specifically associated with boosters and spacecraft.

[b] See Table 4, Section III.

[c] Assuming three additional Saturn 5 flights are required for man-rating and their payload does not include a CSM-LEM

[d] Used for continued spacecraft development (Table 4, Section III).

[e] The lower number assumes that the Saturn 5 launch frequency increases from four per year to six per year after the Saturn 5 is man-rated or during 1969 (whichever occurs last), whereas the higher number indicates a constant Saturn 5 launch frequency of four per year.

[f] Plus the initial R&D investment of a few million dollars.

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ALTERNATIVE APPLICATIONS

Although an earth-orbit-rendezvous contingency plan has been suggested here because of the potential problems involved in man-rating the Apollo Saturn 5 launch vehicle, this mode may also have other applications, such as in connection with rescue missions. Another interesting area, and one we explore briefly here, is the possible application of the contingency plan to the potential problem of spacecraft weight growth. The weight history of the Mercury spacecraft(3) indicates that the weight of the spacecraft increased an average of about 10 lb per week early in the program and then dropped to around 2 lb per week near the end. The weight-growth curve for Mercury is shown in Fig. 4, from which it can be seen that the spacecraft weight increased about 700 lb during the program. Perhaps more significant than the magnitude of the weight growth is the fact that the weight-growth problem was considered as "critical" and one which "almost defied the steps taken to control it."(3) Reference 3 also points out this lesson:

> ...proper planning must account for the inevitable weight growth in the design and development of high-performance spacecraft, since the consequence of not planning are either a degradation of the performance goal or exceeding the capability of the launch vehicle with its attendant delays [to increase booster thrust and propellant load].

Because of the seriousness of this problem, studies of future manned space activities(17) have tried to predict the weight growth of spacecraft (see Fig. 5). As shown in Fig. 5, the expected weight growth for Apollo is between 20 and 30 percent. NASA recently increased the weight of the Apollo spacecraft by about 5 percent and implemented a more stringent weight-control system in order to avoid exceeding the remaining 2 percent unallocated payload margin. If, however, the Apollo spacecraft weight continues to increase, then it appears reasonable to assume that the Saturn 5 launch vehicle will be uprated* rather than sacrificing spacecraft performance.

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*An alternative solution for a spacecraft weight-growth problem is to use dual launches in [illegible]h earth-orbit assembly or

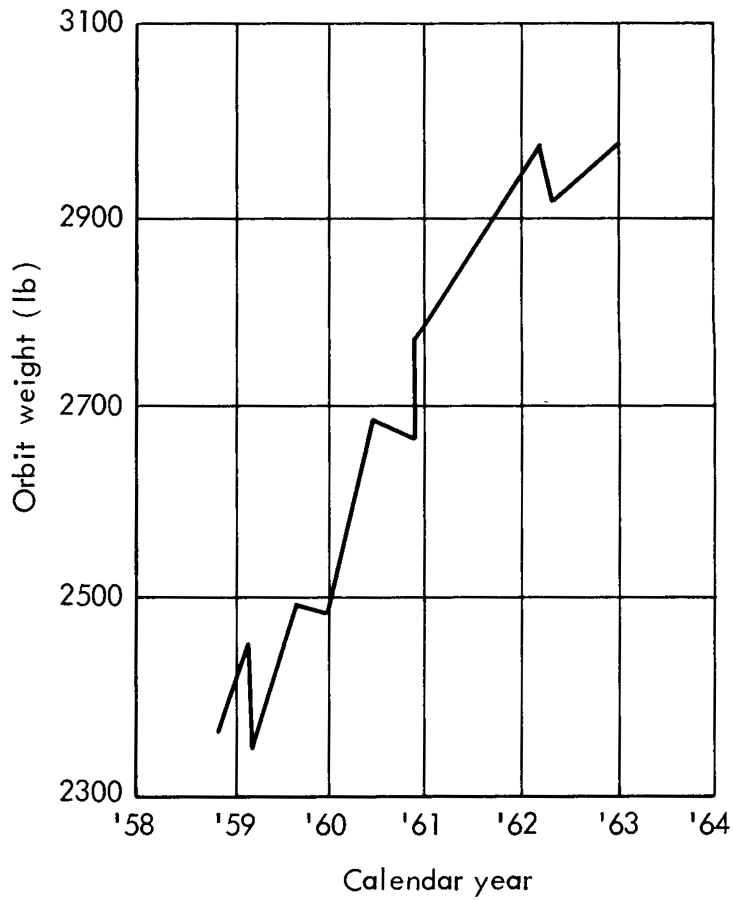

Fig.4—Mercury weight chronology[3]

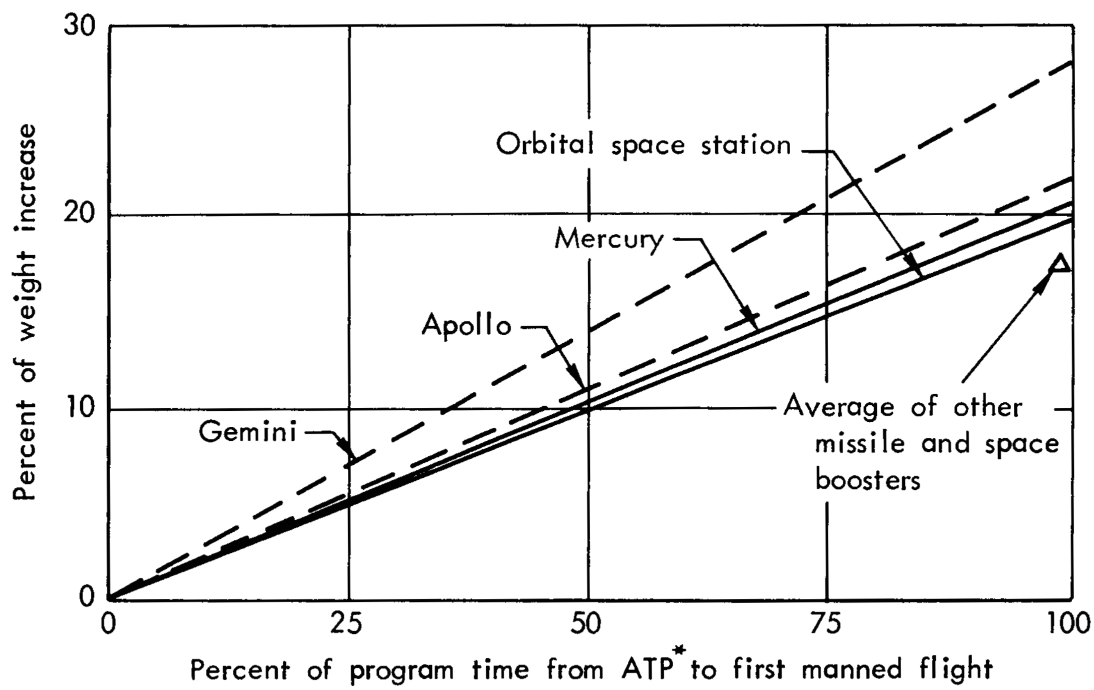

Fig.5—Prediction of spacecraft weight increase(17)

*Authority to proceed.

Several studies have been made of techniques for uprating Saturn 5. While most of these studies have been done in the context of alternative missions for Saturn 5, they illustrate the modifications necessary for a range of payload increases. For example, Table 10 summarizes pertinent results from an uprating study conducted by Marshall Space Flight Center.[18] From this table it can be seen that spacecraft weight growth of about 5 to 10 percent could be handled by increasing the thrust and propellant tankage of the first stage. Such an increase could probably result from a normal product-improvement program. To handle a large increase in spacecraft weight (i.e., 30 to 40 percent), however, requires either the use of new high-performance upper stages or strap-on solid rockets. Either approach will require a lengthy development and flight-test program before the vehicle can be considered man-rated. In addition, cost estimates for a Saturn 5 improvement similar to example C in Table 10 indicate that the non-recurring costs (items such as initial design and development engineering and initial tooling) would be about 50 percent of the present estimate for Saturn 5.[19]

If the weight of the Apollo spacecraft increases sufficiently between now and the time of operational use (1968) to require a substantial uprating of Saturn 5, then the earth-orbit-rendezvous concept offers a means of reducing the time needed before the uprated Saturn 5 can be used as part of manned missions. As before, the spacecraft could be launched by an uprated but not man-rated Saturn 5 launch vehicle, and the men could be sent aloft via a man-rated ferry vehicle. Or, in a program where a new booster is required but the initiation date for manned flight is not critical, then the use of the earth-orbit-rendezvous technique allows postponement of the go-ahead decision for the booster. The length of this postponement would be equivalent

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refueling. An analysis of this approach has not been considered in this Memorandum because (1) no research activity is being considered to support the feasibility of these techniques and (2) to support a spacecraft weight growth of more than about 10 percent necessitates the launching of either two Saturn 5 vehicles or multiple Saturn 1B's plus a Saturn 5.

Table 10

SATURN 5 UPRATING[18]

Saturn 5 Modifications	Spacecraft Gross Weight (lb)	Weight Increase (percent)
A. Standard launch vehicle	90,000	0
B. First-stage thrust increase 8%, plus larger tanks	95,600	6.2
C. First-stage thrust increase 20% plus larger tanks Second-stage mixture ratio increase to 5.4 New high-pressure LOX-LH third stage	124,600	38.4
D. Four 156-in-dia solid strap-on's First- and second-stage tanks increased 10%	133,000	48

to the time normally necessary for man-rating the booster. The advantage of postponing the booster decision is that more knowledge will be available on the operational spacecraft and consequent booster-performance requirements.

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